Modeling and Control of integrated Engine Plant

Takayuki Nakajima, Feifei Zhang, Masanori Ito, Kiyoshi Mishima
Tokyo University of Marine Science and Technical, Tokyo, Japan

Abstract: The diversification of the regulating system was promoted with the development of the computer technology. On the other hand, environmental problems and the energy conservation problem are being valued as for needs of the society. Our research was able to be achieved in such a situation.

Keywords: integrate engine plant, modeling, pressure control, level control, Matlab

1. INTRODUCTION

This paper consider the control problem of integrated engine plant. It is well know that the ship’s machinery plant equips boiler, turbine, and power generator. This system has pressure control, level control, temperature control and electric power control, and each of them is usually controlled independently by PID controller. As these control loops are interfering each other, the stability, efficiency and accuracy are limited with simple PID control. Here we plan to develop a new control technical to improve those qualities and at the same times think about the environmental problems measures. To do this, we construct a experiment system which is composed by a high pressure tank, a water supply pump, a compressor, a water turbine, and a power generator. The amount of tank is 3m$^3$ which is almost as same large as that of 50,000DWT class of the ship. Considering the laboratory use, the steam turbine is replaced by water turbine. To control the amount of power generation, it is need to control the water level, the pressure of tank, and the nozzle location connected water turbine.

As the first step of the research, we made some basic experiments to measure system parameters, response speeds and the mechanism of interference. Then, based on these dates, we derived the mathematic model of total system, and examined its validity by comparing the simulation with the experiment result. A good model was able to be made by repeating this process several times.

Finally, we designed an integrated control method. Noticing the fact that the response speed of each control loop is different, we designed a integrated control algorithm which can avoid interference and make system stable. Also, To confirm this algorithm, we use Real time control tool of Matlab soft were and controlled this plant directly. The experimental results show that the control algorithm is useful. As our plant is of real size, the algorithm developed can be applied to the real ship of the next generation.

Now we are progressing the study to find the control method to improve the efficiency of plant operation.

2. EXPERIMENT SYSTEM

This experiment system is shown in figure 1, which is composed of parts with the following dates.

- a high pressure tank of 3m$^3$
- a pump(10mPa*60m$^3$/h)
- a compressor (8MPa)
- electric heater,
- water turbine (pelton form)
- power generation (10Kw)
- pressure, level, temperature sensors
- control panel

Fig.1 Experiment device externals

The purpose of this system is to generate electricity of 50Hz by water power, and which is further amalgamated together with public electric power. It is known that frequency of electricity is decided by the rotational speed of the water turbine, and the power of the generated electricity changes according to the pressure of water. So, from view point of control, the system can be divided into four sub-control units, the tank joins all units.

(1) Pressure control unit

The unit consists of compressor, tank, pressure sensor, valve and controller.
(2) Level control unit
The unit consists of pump, tank, level sensor, and controller. Here, unlike usual valve control, the water supplying amount is adjusted by inverter controlling of motor speed of pump. It is useful for the saving of energy very much.

(3) Miniature waterpower generation unit
The unit consists of tank, water turbine, Dynamo and controller. The rotational speed, so the frequency of electricity, is adjusted by the position of a nozzle drained off to the water turbine. The power of electricity is decided according to pressure and the level in the tank. Therefore, in this unit, the main amount of the control is flowing quantity.

(4) Water temperature control unit
The temperature control is also possible in our plant, although it is not relate to power generation. This can be used as a load on the output side. The unit consists of heater, temperature sensor, controller.

It is clear that the above-mentioned four sub-systems, which share the same tank, influence each other. While the each amount has been independently controlled by the PID control up to now. Though the PID control has the advantage of easiness, the control accuracy cannot be done well more. As the development of the computer technology, more complex control became possible those days. So, we try to develop a better control technique for such an interference system.

To do this, it is necessary to measure the movement characteristic of a whole system. In addition, it is also important to express the characteristic in the mathematics model. In this paper, we mainly explains the model making process.

3. MODELLING OF EXPERIMENT SYSTEM
When the experiment system was modeled, attention is paid to pressure firstly, the inflow flowing quantity, and the exhalation flowing quantity in a whole tank, and the relational expression between each was requested by using a physical law. Air and water flow in the tank are shown in the Fig.2.

\[
A \times L = P \times V_a = P_a \times V_w
\]

\[
\int = \int (Q_a) dt
\]

\[
Q_a = P_a - P_w
\]

\[
\frac{d}{dt} (G_a) = Q_a \rightarrow G_a = \int (Q_a) dt
\]

\[
Q_w = G_w
\]

a) Air flow in the tank
Based on the Boyle-Charles' law on air, the relation of pressure, volume, mass and temperature of air can be written as follows.

\[
P_a \times V_a = G_a \times R_a \times T_a
\]

At this time, air volume inside the tank is shown with an equation of (2).

\[
V_a = V - V_w
\]

On the other hand, a change in the mass of the air depends on the flux of the gas that flowed.

\[
\frac{d}{dt} (G_a) = \int (Q_a) dt
\]

The flowing quantity is thought to be a difference between the flowing quantity of the gas from the compressor that flows in and the flowing quantity of the gas that flows out from the ball valve.

\[
Q_a = P_a - P_w
\]

The water temperature (Tw) was assumed equal to an atmospheric temperature (Ta)

b) Water flow in, and water flow out
The change in the volume of water in the tank is obtained from the relation between the inflow flowing quantity and the outflow flowing quantity.
Quantity of water in the tank is obtained from the density of water, the water level, and the area of the base tank.

\[ G_w = \rho \times A \times L \]  

(6)

c) Conclusion

The expression that shows the state in the tank is as follows.

\[ L = \frac{\int (Q_{wi} - Q_{wo}) dt}{A \times \rho} \]  

(7)

from the performance of the mechanical system, Flowing quantity from the pump depends on pressure of the tank. (head). According to the reference [2], together with the structure of this system, the relation of tank pressure and flowing quantity can be written as

\[ Q_{wi} = \frac{M}{\rho g H} \]  

(8)

Where

\[ H = \frac{(P_o + P) - (P_a - P_t)}{\rho g} + 2Y \]  

(9)

On the other hand, from equations (1), (3), (4), we get

\[ P_a = \int f(Pa - P_{av}) dt \times \frac{R \times T}{(V - V_{w})} \]  

(10)

The volume "Vw" of water is expressed as follows.

\[ V_w = A \times L \]  

(11)

\[ P_a = \int f(Pa - P_{av}) dt \times \frac{R \times T}{(V - (A \times L))} \]  

(12)

When (7) is substituted to (12), it becomes

\[ P_a = \int [f(Pa - P_{av}) dt \times \frac{R \times T}{(V - \frac{2}{\rho}(Q_{wi} - Q_{wo}) dt)}] \]  

(13)

Thus, the equations (7), (8), (9) and (13) stand for both states of pressure and water level, and their inference.

The unknown number is each air mass flow (Pac, Pav), inflow flowing quantity (Qwi) of water, and outflow flowing quantity (Qwo). And it is understood for pressure to be interfered in the water level.

When modeling this time, the unknown number used the value measured by the experiment.

4. Model Realization by MATLAB simulink

The one that the experimental apparatus was shown in the block chart based on the flow of the signal is Fig3.

The measurement result and the approximated expression were applied based on Fig3. All the above-mentioned elements were modeled by Matlab simulink.

To examine the validity of the model, a real machine and the model were controlled by the same control design. And, validity was judged based on comprising the results.

In the following, we show the results of real machine experiments and model simulation in some cases.

Case 1: single element control

Figure 4 shows the water level control result where pressure is 0.0Mpa, the order of level is from 600mm to 750 mm, the response time is about 100sec.

A blue line shows measurements, and a red line shows the model calculation value.

Figure 5 shows the pressure control result, when water level keeps at 250mm.
Case 2: Multi-element control results

The level and pressure are controlled simultaneously set as
- Pressure: 0.4MPa → 0.5MPa
- Level: 250mm → 400mm

The figure 6 and figure 7 show those results.

Other water levels and pressures are also tested.

5. Conclusion

1) About the validity of the model

It has been understood that both of the result of the simulation that uses the model and the result of comparing measurements of a real machine do not have so many differences.

However, measurements are picked up the noise by the signal and have vibrated. Therefore, it has vibrated somewhat in the stable state.

2) Result

The characteristic of the actual experiment device was identified by the research, and it was possible to model.

As a result, the control design can be done more efficiently than the experiments that use a real machine.

However, measurements have become situations of vibrating by the noise in the stationary state. It is thought that putting the filter on the signal, and improving the device the influence of the noise are necessary as measures.

3) Consideration

Using this model does the control design, and a more efficient control will be done in the future.

Finally, Control interfered each other water level, pressure, and temperature, and it is necessary to do the control design that the amount of power generation suppressed the interference with the element best as much as possible.

REFERENCES
